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BREAD

AND

THE PRINCIPLES OF BREAD MAKING.

BY

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PREPARED UNDER THE SUPERVISION OF THE OFFICE OF EXPERIMENT STATIONS.

A. C. TRUE, Director.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., January 20, 1900.

Sir: I have the honor to transmit herewith an article on bread and the principles of bread making, prepared by Miss Helen W. Atwater, in accordance with instructions given by the Director of this Office. In preparing this bulletin Miss Atwater has consulted the available sources of information, including standard works on the subject, and has prepared the material for publication under the supervision of Director C. D. Woods, of the Maine Agricultural Experiment Station, who for some time has been immediately concerned with the investigations conducted under the auspices of this Office which have had to do with bread and bread making.

Perhaps no topic connected with the subject of human food is of more general interest than bread, and this bulletin, which summarizes the most recent information on the subject, is believed to be useful and timely, and its publication as a Farmers' Bulletin is, therefore, respectfully recommended.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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BREAD AND THE PRINCIPLES OF BREAD MAKING.

INTRODUCTION.

There is hardly any food, except milk, which is so universally used as bread; and not only is it now known almost everywhere, but since history first began it has in some form or other made one of the staples of diet among all but the most savage peoples. In the earliest historical records it is spoken of, and the wild tribes which to-day inhabit South Africa know something of its use. Of course the bread made by the Kafir to-day, or by the American Indian three hundred years ago, is very different from our own. It would be interesting to trace the relationship between the bread-making processes of given peoples and their rank in the scale of civilization. The Kafir simply grinds his grain between two stones, makes a paste of this meal and water, and bakes it in the ashes of his camp fire; Israel, in Egypt, ate leavened bread; the ancient Greeks cultivated the yeast plant; in Pompeii an oven was found containing eighty-one loaves of bread not unlike our own; the Swiss peasant still bakes his weekly loaves in the village oven; and so on, to the mammoth bakeries and innumerable fancy breads of our own large towns. Such a classification would not be utterly absurd, for except among the lowest savages and in the extremest climates some kind of grain is recognized as a necessary food, and bread furnishes it in one of its most convenient forms—that is, a form in which it yields the greatest amount of nourishment for the least labor and cost. No wonder, then, that the more intelligent a people the better bread they make.

The reason for this importance of bread is very simple. Ever since the far-off days when our forefathers first found the wild cereals, or began to cultivate them, men have known that food prepared from them would support life and strength better than any other single food except milk. The diet of the poor in India and China often consists almost entirely of wheat or millet cakes or rice, and although in our own land the ease with which we can get other foods makes bread seem less important, there are still many districts in Europe where the people eat very little else. To a large part of mankind it is still the staff of life, and if they pray for their daily bread they mean it literally.

In regard to its ingredients, bread is one of the simplest of our cooked foods, but in regard to the changes which the raw materials must undergo to produce a finished loaf, it is one of the most complicated. Flour, water, a pinch of salt, and a little yeast—the necessary things can be counted on the fingers of one hand, yet one of the few books which describes the processes of bread making with any degree of completeness is a large volume of over 600 pages. It is the purpose of this bulletin to give a brief account of these processes—to describe the raw materials from which the bread is made, and the changes which they undergo in the preparation and baking of the dough, with the significance of each to the quality of the bread and its value as food. But before going into a detailed description of these processes it will, perhaps, be well to recall what the main steps in bread making are.

Beginning back in the flour mill, the grain is ground into powder, the coarser parts of which are sifted out as bran, while the finer constitute our flour. Once in the baker's hands, the flour is mixed with water and yeast, or something which will produce the same effect. When this paste or dough, containing yeast, is set in a warm place the yeast begins to "work," as we say, and the dough to "rise;" in other words, the yeast causes a change known as alcoholic fermentation to set in, one of the principal results of which is the production of carbon dioxid gas. If the dough was well mixed, this gas appears all through it, and, expanding, leavens or raises it. After the yeast has worked sufficiently the dough is shut up in a hot oven. Here the heat kills the yeast and prevents further alcoholic fermentation, causes the gas to expand and stretch open the little pockets which it forms between the particles of dough, and changes some of the water present into steam, thus raising the loaf still more. Further, the heat hardens and darkens the outer layers into what we call the crust. The sum of these changes in the oven we call baking. When they have been continued long enough our bread is "done," ready to cool and eat.

GRAINS AND FLOURS.

Flours, as everyone knows, are made by grinding the grains of the various cereals, wheat, rye, barley, oats, maize, millet, rice, etc. Of these, wheat is the most important partly because it can be cultivated in any temperate climate, but chiefly because it yields the flour best suited to bread making, the aim of which is to produce the most appetizing and nutritious loaf at the least expense. While the various cereals differ largely in their chemical composition, most of them are very similar in the structure of their grains, so that if we study the formation and milling of wheat, we can easily understand the production of flour from the others.

WHEAT.

Structure.—The wheat grain (fig. 1) is a small oval seed, which can be easily thrashed from the stalk on which it grows. Its six outer layers are known to the miller as the bran. Of these, the three outermost form what is called the skin of the grain and constitute 3 per cent, by weight, of the entire seed. The three remaining layers of the bran form the envelope of the seed proper. The outer one is known as the "testa," and contains the greater part of the coloring matter of the bran. Inside it lies a thin layer of membrane. These two together form 2 per cent, by weight, of the entire grain. The innermost layer of the bran, called the cereal or aleurone layer, is made up of rectangular cells, filled with a nitrogenous substance known as cerealin or aleurone. Its weight is about 8 per cent of that of the entire grain, making the total weight of the bran about 13 per cent. In milling it is exceedingly difficult to separate these three inner layers of the bran. Within the cerealin layer lies the endosperm, as the portion of the grain adjacent to the embryo is called, which constitutes the larger part of the grain and consists of irregular shaped cells containing starch granules. At the lower end of the grain, almost surrounded by the endosperm, lies the germ or embryo. A portion of the embryo is called the scutellum. This serves a special purpose in germination. When the grain has thoroughly ripened and has been placed in favorable conditions, this embryo will develop into a new plant; as it begins to grow it will feed upon the starch and other substances in the endosperm.

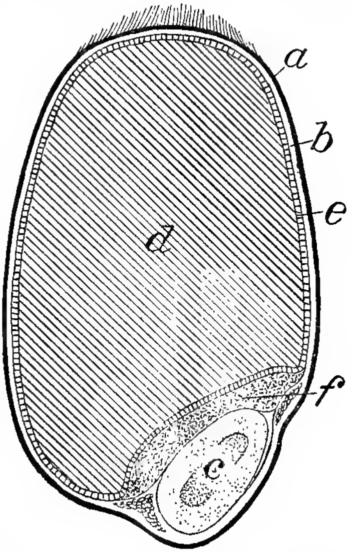

FIG. 1.—Section of grain of wheat: *a*, skins and testa; *b*, membrane; *c*, embryo; *d*, endosperm; *e*, cereal or aleurone layer; *f*, scutellum.

Composition.—The five outer layers of the bran contain very little except cellulose, a woody, fibrous substance forming the cell walls. When burned, the ash of bran is found to contain a fairly large proportion of phosphoric acid, potash, and small amounts of other mineral matters. The cereal layer is, of all parts of the grain, the richest in nitrogenous substances, the chief of which is the cerealin from which it takes its name. The endosperm contains, besides the cellulose of its cell walls, large quantities of starch, a little sugar, and a nitrogenous substance known as gluten. The germ contains cellulose, nitrogenous substances, sugar, and a very large proportion—9 to 12 per cent—of fat.

Grain, being hygroscopic—that is, having the power of absorbing water from the atmosphere—varies with the weather in the amount of moisture which it contains; similarly, wheat grown in a wet season or a humid climate holds a larger percentage of moisture than the same kind grown under drier conditions. Thus English wheat contains 3 or 4 per cent more water than American. From comparison of many analyses, the average weight of the water in the grain is found to be about 12 or 13 per cent of its total weight.

Different kinds of wheat also vary as to the amount and quality of gluten which they contain. As gluten is one of the most important constituents of the wheat, the baker should know the character of the gluten in the flour he uses. The so-called "hard" wheats are rich in gluten of a strong, tenacious character, while "soft" wheats contain less gluten and proportionately more starch. The gluten of hard wheat can be mixed with large amounts of water, and produces a large loaf from a comparatively small quantity of flour. Soft wheat, on the other hand, while it does not yield so large a loaf, makes a bread containing less water, and having a milder and more agreeable flavor.

It is useful for those interested in milling to know what parts of the grain will be most valuable in yielding a nutritious flour capable of making a white, well-raised loaf. In considering the nutritive value of flour let us remember the principal kinds of nutrients which the body needs: (1) The nitrogenous substances, called protein compounds or proteids, typified by the white of egg and the lean of meat, and chiefly represented in wheat by the cerealin and the gluten—these are the tissue-building materials of our food, though they also furnish energy; (2) the carbohydrates, principally starch and sugars, found mainly in the endosperm, and serving the body as fuel to produce energy for warmth and muscular work; (3) the fats, occurring principally in the germ of the grain, and being valuable to the body as fuel, and (4) mineral matters, seen in the ash, especially that of the bran, and providing material for bones, teeth, etc. We must also bear in mind that it is not only the chemical composition of a substance which determines its food value, but also the amount of nourishment which the digestive organs can extract from it—in other words, its digestibility.

The abundant cellulose in the bran and the coloring matter in the testa tend, if left in the flour, to give it a coarse, dark character very detrimental to the appearance of the bread. Accordingly, until recently, that flour was quite generally considered the best which had the least of the bran in it. Lately, however, much stress has been laid on the nutritive value of the mineral matters and the cerealin of the bran, consequently a great effort has been made to get a fine flour which shall include the entire wheat grain. Such flour can not produce as white a loaf, and, what is still more to the point, it is doubtful whether the cerealin is thoroughly digested by the human stomach; moreover, the sharp, rough particles of the cellulose in the bran are said to irritate the membranes of the alimentary canal and thus to hasten the passage of the food through the intestines. This would tend to diminish its digestibility, although it might be advantageous in counteracting a tendency to constipation. It would seem, then, that the value of bran in flour, unless it can be ground more finely than at present, is at least questionable. The germ, though rich in fat and ash, is also of doubtful value in the flour, as it tends to darken the color, and its fat occasionally grows rancid and spoils the taste.

The endosperm is by far the most important contributor to the flour. In its starch lies the chief nutritive ingredient of bread. The gluten, as the principal nitrogenous constituent of wheat is called, is equally necessary; mixed with water it forms a tenacious, elastic body which expands under the pressure of the gas from the yeast until the dough is full of gas-filled holes whose walls of tough gluten do not allow the gas to escape, and thus make the dough light and porous. The more gluten a flour holds, the more water it can be made to take up in dough, and the greater will be the yield in bread from a given amount of flour. Hence flours are classified as "strong" or "weak" according to the proportion of gluten which they contain and their consequent ability to yield bread. Gluten has also a high nutritive value as an easily digested proteid.

Milling.—When people first began to grind their grain, they did so simply by crushing it between any two stones which happened to be handy; a little later they kept two flat ones especially for the purpose, one of which they soon learned to keep stationary while the other was turned about on it. At first each woman ground the meal for her own family on her own stone; but after treadmills, windmills, and, later, water wheels came into use all the grinding was done by the professional miller in the village mill. In feudal days the lord forced his tenants to have their grain ground in his mill, even to bake their bread in his oven, and charged a good round toll for the use of each. Various devices for grinding and sifting the grain have gradually been invented, until to-day we have mills covering acres of ground and doing apparently impossible things with the grain. In Hungary the old Roman system of cylinder milling, similar in principle to an ordinary coffee mill, has been developed, but elsewhere the systems which are known as high and low milling are more common. Here we have the original system of crushing between two stones, or rollers, but so elaborated as to be almost unrecognizable. In low milling the grain is ground in one process between two crushers placed as near together as possible. Graham flour and that commonly known as "entire-wheat flour" are prepared in this way. Of these only the former, invented by the American physician, Dr. Sylvester Graham, really contains the entire grain; it is made by simply washing and cleaning the grain and then grinding it between two stones or rollers, whose surfaces are so cut as to insure a complete crushing of the grain. Entire-wheat flour is made in much the same way, except that after being washed the grains are run through a machine which removes the three outer layers, and then are ground. In this way the supposedly valuable cerealin layer is included without the almost useless cellulose of the outer bran. In high roller milling the grain is washed and skinned as in milling entire wheat, and then is run through five or even more pairs of rollers, each successive pair being set a little nearer together than the last. After each grinding, or "break," as the miller terms it, the meal is sifted, and the leavings of each sifting, called "tailings," are themselves ground and sifted several times. In a mill where the grain goes through a series of six straight breaks, there are as many as eighty direct milling products, varying in quality from the finest white flour to pure ground bran. Careful millers always try to grind as near the cerealin layer as possible, and to leave as much of the germ in the flour as is consistent with a good color. To make sure that each product is up to the standard set up for it in the mill, samples of it are tested every hour and the milling is regulated accordingly.

The so-called "straight-grade" flours ordinarily seen on the market consist of the siftings of all the breaks plus the first product of the first tailings. "Patent" and "baker's," or "household," flours are varieties of the straight-grade flours. The accompanying tables show the chemical composition of various milling products and American wheat flours:

Analyses of wheat and the products of roller milling.[1]

	Water.	Protein.	Fat.	Carbohydrates.		Ash.
				Starch, etc.	Crude fiber.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Wheat as it enters the mill	9.66	14.18	2.61	69.94	1.70	1.91
First break	8.23	14.18	2.68	71.56	1.62	1.73
Sixth break	7.66	16.28	5.34	59.42	5.60	5.68
Bran	10.91	16.28	5.03	56.21	5.98	5.59
Tailings from reduction No. 5	12.12	16.63	3.85	63.93	1.18	2.29
Second germ	8.75	33.25	15.61	35.19	1.75	5.45
Entire-wheat flour	11.4	13.8	1.9	71.0	.9	1.0
Graham flour	11.3	13.3	2.2	70.5	.6	1.8
Patent roller-process flour:						
Bakers' grade	11.9	13.3	1.5	72.0	.7	.6
Family and straight grade	12.8	10.8	1.1	74.6	.2	.5
High grade	12.4	11.2	1.0	74.7	.2	.5
Low grade	12.0	14.0	1.9	70.4	.8	.9

[1] U.S. Dept. Agr., Division of Chemistry Bul. 13, pp. 1226-1228, and Office of Experiment Stations Bul. 28 (rev. ed.), pp. 57, 58.

If, as often happens, it is desirable to blend two kinds of wheat in order to obtain a flour with the average of their qualities, the grains are usually mixed before milling. Sometimes the miller, or even the baker, mixes two pure flours, but such a proceeding is less reliable.

Very complicated chemical tests are necessary to determine the exact quality of a flour, but there are certain general rules by which a good bread flour may be judged offhand. Its color should be white with a faint yellow tinge; after being pressed in the hand it should fall loosely apart; if it stays in lumps it has too much moisture in it; when rubbed between the fingers it should not feel too smooth and powdery, but its individual particles should be vaguely distinguishable; when put between the teeth it should "crunch" a little; its taste should be sweet and nutty without a suspicion of acidity.

Impurities and falsifications of wheat flour.—The impurities which may accidentally slip into a bag of grain, or even into the flour made from it, consist chiefly of the seeds of other plants, and of blighted or molded wheat. The foreign seeds most to be dreaded are perhaps cockles and darnel, and both should be carefully guarded against—cockles because they injure the color of flour and bread, and darnel because it is commonly regarded as poisonous. Other foreign seeds may not be equally dangerous, but they should be removed with equal care, as they lessen the nutritive value and the strength of the flour. Molds and other fungus growths often give a musty odor and taste to grain or flour which has been kept in a damp place. Both these classes of impurities are easily avoided by careful milling and storing, and are not so much to be feared as the foreign substances which are added to the flour to cheapen its cost or improve its appearance. Those used to cheapen the cost are usually rye flour, corn (maize) flour, rice meal, potato starch, and meals from various leguminous plants, such as peas or beans. They are not harmful in the food and sometimes improve the color of the bread; nevertheless they are fraudulent because they lower the quality of the flour without harming its appearance. The mixture is sold as flour, and thus the purchaser secures an adulterated article under a false name, and often at the same price as pure goods. Mineral substances, such as alum, borax, chalk, carbonate of magnesia, bone, etc., are occasionally put into the flour to whiten it or to neutralize its acidity, but as these are more often used by the baker than by the miller, their effect will be discussed later (p. 31).

RYE.

The grain of rye is darker in color than that of wheat, but is otherwise similar in appearance. It differs, however, in one important particular—its gluten has not the same elastic, tenacious quality and does not yield so light and well-raised a loaf. Although this fact and its dark color make it less desirable than wheat flour, it is second in importance as a breadstuff. It is more easily cultivated than wheat, especially in cold countries, and consequently costs less. In many parts of Europe it practically replaces wheat among the poor and in the rations furnished the army. When it is milled entire, as it usually is, it contains more protein than wheat flour, but is probably less completely digested. Wheat and rye flour are often used together in bread.

BARLEY AND OATS.

These cereals are so seldom used in bread that a short description of them will suffice. In general structure their grains are not unlike those of wheat; in barley the proportion of the bran to the entire grain is about 21 to 79, in oats 44 to 66; the percentage of moisture in them is much lower than in wheat; their gluten is even less tenacious than that of rye; though flours made from them without bran contain a high proportion of nutritive ingredients, they also contain a large amount of indigestible cellulose and are quite unsuited to yield a light, attractive bread.

CORN, OR MAIZE.

This cereal, commonly known to us as Indian corn, and on the Continent of Europe as maize, or Turkish wheat, is a native of America. It is commonly grown in North and South America, northern Africa, India, and southern Europe, especially Italy and the Balkan regions, and is slowly being introduced into other European countries. The skin of the kernel is thin and tender, the endosperm abundant, white, and mealy, the germ comparatively large. See fig 2. The kernels are generally white or yellow. Compared with wheat, maize is rich in fat, poorer in cellulose and protein, and about equal in carbohydrates, mineral matters, and moisture. Most of its fat is in the embryo or germ, which is often removed in milling to prevent the flour or meal becoming rancid. Maize flour makes very nutritious and appetizing unleavened bread, hoecake, johnnycake, etc., but this dries so quickly that it must be eaten fresh. Maize flour contains no tenacious gluten-like proteid, and therefore can not be used alone to produce a good loaf raised with yeast. Much corn bread and other foods made from corn meal are eaten in the United States. In Italy corn-meal mush, or "polenta," as it is called, forms the principal article of diet of the peasants in large districts throughout a considerable part of the year. In Servia the unripe corn is eaten much as we use it, and corn-meal bread and mush are staple articles of diet.

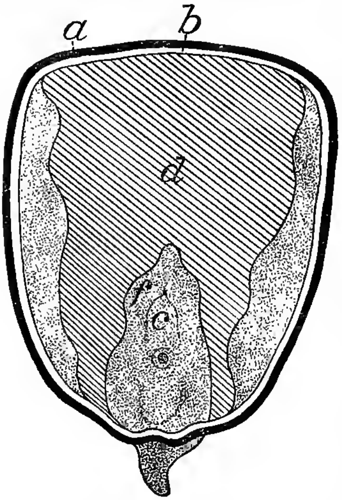

FIG. 2.—Section of grain of corn: *a*, skin and testa; *b*, membrane; *c*, embryo; *d*, endosperm: *f*, scutellum.

RICE, MILLET, BUCKWHEAT, ETC.

Rice is a very important cereal in China, Japan, and other oriental countries; much millet is eaten in China, India, and Russia; sesame is also largely used by the native races of India, and in the United States buckwheat is often made into batter cakes; but none of these as a rule take the place of bread to any extent except in some oriental countries. In some regions of Russia, however, buckwheat porridge is the principal cereal food. Kafir corn is used in the United States to a limited extent for batter cakes, etc., though in its native land it is the principal cereal of large numbers of Abyssinians, Kafirs, and other races.

The following table gives figures by which the chemical composition of our most common cereals may be easily compared:

Composition of cereals.[1]

	Water.	Protein.	Fat.	Carbohydrates.		Ash.
				Starch, etc.	Crude fiber.	
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Barley	10.9	12.4	1.8	69.8	2.7	2.4
Buckwheat	12.6	10.0	2.2	64.5	8.7	2.0
Corn (maize)	9.3	9.9	2.8	74.9	1.4	1.5
Kafir corn	16.8	6.6	3.8	69.5	1.1	2.2
Oats	11.0	11.8	5.0	59.7	9.5	3.0
Rice	12.4	7.4	.4	79.2	.2	.4
Rye	11.6	10.6	1.7	72.0	1.7	1.9
Wheat:						
Spring varieties	10.4	12.5	2.2	71.2	1.8	1.9
Winter varieties	10.5	11.8	2.1	72.0	1.8	1.8

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 11, pp. 16, 17, and Bul. 28 (rev. ed.), p. 56.

YEAST AND OTHER LEAVENING AGENCIES.

THE THEORY OF FERMENTATION.

When, in beer making, a little yeast is put into a vat of warm, sweet liquid, bubbles gradually appear until the whole mass seems to be boiling. If the liquid is analyzed after the yeast has so worked in it for a time it will be found to contain less sugar than at first; the amount of yeast will have increased, and alcohol and carbon dioxid will appear in considerable quantities. The explanation is this: The yeast, which is really a mass of tiny plants, has reproduced again and again, and in this growth has fed upon the sugar of the liquid and given off alcohol and carbon dioxid. Such a phenomenon is called alcoholic fermentation, and is essentially the same as that which "raises" a loaf of bread. Such fermentation is by no means the only kind which occurs in common life. The souring of cider into vinegar, for instance, is due to another kind. In that case a variety of microscopic plant develops in the cider, and in so doing produces acetic acid, which gives vinegar its characteristic taste. This is called acetic fermentation. Similarly, if another variety of bacteria get a chance to develop in sweet milk they give rise to lactic fermentation, during which is produced the lactic acid which turns the milk sour. Rancidity of butter is due to the so-called butyric fermentation. Here the bacteria yield butyric acid, which gives the butter its disagreeable taste and odor.

These microscopic plants and many others are widely distributed in the air, and often find their way accidentally into different materials, where they grow and multiply, causing fermentation, just as thistle seeds, for instance, are blown about in the air until they lodge in some favorable spot and grow. At other times special forms of ferments in so-called "pure cultures" are purposely added to some material, just as seeds of larger plants are purposely sown in the garden. Thus pure cultures of certain microscopic organisms are added to cream to improve the flavor of butter and make it uniform in quality. This insures a special fermentation instead of the accidental fermentation which would otherwise occur. The term fermentation was first applied to the action of yeast plants on sugar with the formation of carbon dioxid and alcohol. There is another class of chemical changes to which the term fermentation is applied. Such changes are produced by chemical substances called enzyms, which are not living organisms, but which are produced by living organisms. Ferments are therefore divided into two classes, (1) the organized ferments, such as yeast, bacteria, etc., and (2) unorganized ferments, or enzyms. Human saliva contains an enzym called ptyalin. When mixed with food in the mouth it changes starch into a form of sugar, which is more easily digested than starch. In grain there exists an enzym called diastase, capable of producing a similar effect on starch. The pepsin and trypsin of the digestive juices are also enzyms.

It is a peculiar feature of fermentation that the microscopic plants which cause it affect a much larger amount of the material on which they feed than goes to their own development. Thus yeast converts much more sugar into alcohol and carbon dioxid than it consumes in its own growth and reproduction. When the fermentation ceases the yeast plant remains; in other words, the fermentation has been produced without changing the nature of the agent producing it. In the same way the enzyms cause fermentation without being themselves changed. Though so much has been learned in recent years concerning fermentation, there still remain many things to be explained. We know what changes take place and under what conditions, but just why they take place is not so clear. It is a remarkable fact concerning ferments that the substances they produce, in time put a stop to their activity. Thus the alcohol produced by the yeast in time is sufficient to hinder the growth of the yeast plant and ultimately to kill it. If, however, the products of this activity are removed, the ferments resume work.

YEAST.

Keeping the above facts in mind, it is easy to understand the leavening effect of yeast in dough. The yeast, "working" in the warm water and flour, feeds on sugar[1] originally present or else produced from the starch by diastase, grows and spreads throughout the dough, at the same time giving off carbon dioxid gas, which forces its way between the tenacious particles of gluten and lightens the dough.

Scientifically speaking, yeast is a minute fungus of the genus Saccharomyces. A single plant is a round or oval one-celled, microscopic body (fig. 3), which reproduces in two ways—either by sending out buds which break off as new plants, or by forming spores which will grow into new plants under favorable conditions. It grows only in the presence of moisture, heat, and nutritive material. If the moisture is not abundant the surrounding substances absorb that which already exists in the yeast cells and so prevent them from performing their functions. Yeast develops best at a temperature of 77°–95° F. (25°–35° C.). We have already seen how yeast uses up sugar in its growth. It is also believed that some nitrogen is necessary for the best development of yeast and that such development is most complete in the presence of free oxygen, but why these things are so is not yet clearly understood.

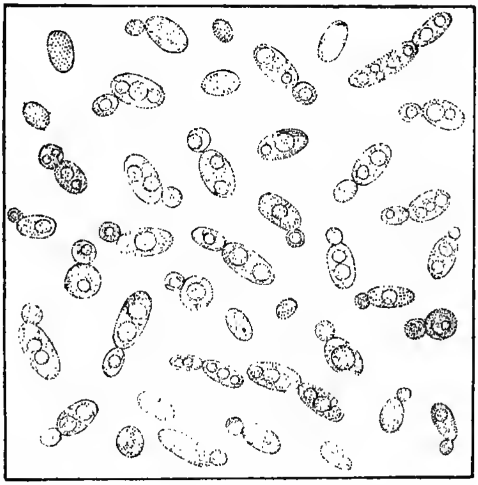

FIG. 3.—Yeast plant highly magnified.

Yeast is literally as old as the hills. It must be present in the atmosphere, for if a dish of malt extract, originally free from yeast, be exposed to the air, alcoholic fermentation, such as could be produced only by yeast, will soon set in. Such yeast is known as "wild yeast" and all our yeasts have been cultivated from it. The oldest method of growing yeast is perhaps that used by the Egyptians. A little wild yeast was obtained and set in dough, a portion of which was

[1] The sugar upon which yeast is said to feed in its growth is not necessarily such sugar as we ordinarily use to sweeten our food. The word sugar is here used in its broader, scientific sense. All starches and sugars, it will be remembered, are grouped together by chemists under the name of carbohydrates. They are chemical compounds of carbon, oxygen, and hydrogen and differ from each other in the proportion of oxygen and hydrogen to carbon which they contain. For a more extended discussion of sugar see U. S. Dept. Agr., Farmers' Bul. 93.

saved from the baking; there it went on developing as long as materials held out, and thus the bit of dough or "leaven" contained so much yeast that a little of it would leaven the whole loaf. It was such leaven as this which the Israelites had not time to put into their bread when they were brought out of the land of Egypt. A microscopical examination was recently made of some bread over four thousand four hundred years old, found in Egypt, with other remains of a long-vanished people. It was made of ground barley and the yeast cells were plainly visible. A similar process of raising bread with "leaven" is still carried on in some regions of Europe. The "wet" or "potato yeast," so common in this country before the days of patent yeast, was made by a similar method. Wild yeast was cultivated in a decoction of hops or potato and water and some of the material thus obtained was mixed with the dough. The "barms" so much used in Scotland are made by letting yeast grow in malt extract and flour (p. 22). Brewers' and distillers' yeasts are taken from the vats in which malt extract has been fermenting. Compressed yeasts are made by growing yeast plants in some sweet liquid, then drying the material to check their growth, and pressing it; sometimes a little starch is added to make the little cakes keep their shape. The strength of any yeast depends on the care with which it is made and preserved. Ordinary brewers' yeasts are likely to be full of the bacteria which set up lactic or other fermentations in the bread and give it a disagreeable taste and odor. They are very susceptible to changes in the weather and can not be always relied on. Compressed yeasts, if carefully made, are more uniform in strength and composition. Usually a few of the microscopic plants or bacteria other than yeast are allowed to remain, as the slight acid taste they give to the bread is considered an advantage.

SUBSTITUTES FOR YEAST.

Partly because yeast is uncertain in its workings, partly, too, because it uses up some of the nutritive ingredients of the bread by feeding upon them, attempts have been made to find some substitute for it. Various chemicals have been used to produce carbon dioxid gas in the dough. The first noteworthy attempts were made about fifty years ago at Harvard University and in Germany. Yeast powder, as the American preparation was called, was a mixture of an acid and an alkaline powder—the former calcium phosphate and the latter bicarbonate of soda and potassium chlorid. When duly mixed with the dough these were supposed to give off carbon dioxid as effectively as yeast. Liebig, who calculated that in Germany the daily loss of material by the growth of the yeast plant was, if saved, sufficient to supply 400,000 persons with bread, made a great effort to introduce a similar preparation into Germany, but with little success.

Numerous baking powders made from various chemicals are in the market now. The self-raising flour used in the United States Army is a flour ready mixed with such a preparation. The chief objections to such yeast substitutes are that unless carefully prepared they may be inefficient or harmful, that they are easily adulterated, and that bread made from them is usually rather tasteless, lacking the flavor and aroma which good yeast imparts. Soda, cream of tartar, or saleratus biscuits are made on the same principle, but with less powerful leavening agents.

The "aërated bread" so popular in London is made by a different method, invented by the English physician Dauglish in 1856. According to this method, the water used for wetting the dough is directly charged with the requisite amount of carbon dioxid gas and then mixed with the flour in a specially constructed machine. Sometimes a little fermented barley infusion or wort, as it is called, from a brewery, is put into the water. This aids it in absorbing the gas, renders the gluten more elastic, and improves the flavor of the bread.

The so-called "salt-rising" bread is interesting as an illustration of self-raised bread. In it the ferments originally present or acquired from the air produce the fermentation which leavens it. To make it, warm milk and corn meal are mixed together into a stiff batter, which is left at blood heat until the whole mass is sour; that is, until the ferments present have produced fermentation throughout. Next a thick sponge is made of wheat flour and hot water, in which a little salt has been dissolved. This sponge and the sour batter are thoroughly kneaded together and set in a warm place for several hours. The leavening action started in the batter spreads through the dough and produces a light, porous loaf, which many persons consider very palatable. Such bread is quite free from acidity, as the presence of the salt prevents undesirable fermentation.

RAISED BREAD.

Ordinarily a baker mixes his dough with water, and most of the experiments and analyses quoted here have been made with such bread. Sometimes, especially in private families, milk is used in the place of water. Such dough is slower in rising, but makes an equally light loaf. Milk bread naturally contains a larger percentage of proteids and fats than water bread and is equally digestible. Its use is by all means to be advocated, especially on farms where skim milk is abundant.[1] When water is used it should, of course, be as pure as possible. Its hardness or softness makes little difference in the quality of the bread, though perhaps the softer water is to be preferred. Salt is used in bread because it imparts a flavor without which bread is usually

[1] See articles on the digestibility of bread in Maine Sta. Rpt. 1898.

considered insipid, and because it exerts a retarding influence on the chemical process by which starch is converted into sugar and on fermentation.

PREPARATION OF THE DOUGH.

There are various methods of mixing dough, but certain general rules apply to them all. As yeast develops best at a moderately high temperature (77°–95° F.), the materials of the dough should be at least lukewarm, and the mixing and the raising should be done in a warm place, as free as possible from drafts. If all portions of the dough are to be equally aërated by the gas from the growing yeast, the latter must be thoroughly mixed with the flour and water; moreover, as the presence of oxygen aids the growth of the yeast, all parts of the dough should be exposed to the air; both these results are accomplished by the kneading. Too little yeast will, of course, yield a badly raised loaf, but too much yeast is just as dangerous; the bubbles formed in the gluten of the flour, unable to resist the pressure of the excessive amount of gas, break open, the gas escapes, and the dough becomes heavy and soggy. Too much yeast also gives an unpleasant, "yeasty" taste to the bread, due partly to the presence of superfluous yeast cells, but more especially to other microscopic growth producing fermentations. Even when used in small quantities yeast has a decided influence on the flavor of the bread. The amount of yeast which should be used depends on the strength of the flour. A flour in which the gluten is abundant and tenacious can resist a much stronger pressure of gas than one poor in gluten, which, if it does not fall entirely, is likely to make a loaf with large holes and heavy, badly raised masses between. Similarly, the proportion of water which should be used varies with the strength of the flour. The standard cookbooks suggest an average of about three parts of flour to one of water, the ratios changing with the quality of the flour. In general, nothing but practical experience with his materials can teach a baker the exact quantities which he should mix. Salt, as has been said, tends to retard fermentation, and consequently should be added toward the end of the mixing; then it is useful because it checks lactic or butyric fermentations, such as often follow the alcoholic fermentation.

It seems almost superfluous to say that the greatest cleanliness should be observed in kneading bread. Most household cooks maintain that it is impossible to mix dough as evenly with a knife or spoon as with the hands. Perhaps, where bread is made in small quantities and every precaution is taken against uncleanliness, this use of the hands may be tolerated, but not in wholesale bakeries where dough is mixed in such large quantities that the kneading is violent physical exercise and the worker is unable to take his hands from the dough long enough to wipe his dripping forehead. In such establishments the modern kneading machines, in which revolving metal blades do the work of the hands, are surely to be advocated, and in general those breads are to be recommended which are made with the aid of machinery so arranged that none of the materials need be touched by hand from the time they enter the bakery until the finished loaves are taken from the oven. Every utensil used for bread making should be scrupulously clean, not only on principles of general decency, but because otherwise bacteria may get into the dough and produce harmful fermentation.

The ways of mixing dough most used in this country by bakers are probably those known as "straight dough" and "sponge dough."

Straight dough, or "offhand" dough, as it is sometimes called, is made by mixing all the materials at one time, and then setting the mass in a warm place to rise for ten hours or more before baking. It requires more yeast and stronger flour than other methods in which the yeast is allowed to grow in an especially favorable medium before being mixed with the main dough, and needs a longer time to rise, but on the other hand gives an unusually large yield in bread. It is convenient in family bread making, especially when strong, compressed yeast is used, as the dough can be mixed overnight and baked in the morning. Some wholesale bakers dislike it because the dough is stiff and hard to knead, because the large quantities of materials used at one time require extensive kneading apparatus, and because the bread is usually coarse in texture, with a raw, grainy taste, due to the strong flours used.

Sponge dough.—This method is best adapted to fancy working, and makes equally good crusty loaves or light biscuit. To make the "sponge," as the bread mixture is commonly called, the yeast is allowed to work for eight or ten hours in a portion of the flour or water. This is then mixed with the remaining materials and left to rise a few hours before baking. The sponge is "slacker"—that is, contains more moisture than offhand dough—and thus gives the yeast a better chance to work. Bakers usually set their sponge with a strong flour, which gives a light, elastic quality; a little salt is put into it to prevent lactic fermentation. A weaker flour may be used in the second mixing, as the greater part of the gas has already been given off in the sponge, and no great pressure will come on the newly added gluten. If strong flour be used instead, the bread yield will be greater, but the soft, sweet flavor imparted by the weaker kinds will be replaced by the harsh taste noticed in bread made from offhand doughs. Great care must be taken to mix the second lot of flour in thoroughly, or the bread will be full of hard lumps on which the yeast has had no effect. Sponge-made bread usually rises evenly and well, and can be worked into almost any shape. It has the further advantage of keeping well. It requires longer labor than the method described before, still the difference is really that between two short kneadings in soft dough and one long one in stiff. Like offhand dough, it can be started the night before it is baked.

After mixing his dough in the way he considers most desirable, the baker sets it in a warm place to rise. Here the yeast continues to work and the gas given off stretches the spaces between the particles of dough. If the gas is allowed to go on increasing until its pressure is greater than the elasticity of the gluten can resist, the latter breaks apart, leaving large holes throughout the dough. If such "overproved" dough is kneaded a little before it is put into the oven the excessive gas will be forced out and the holes will be more regular.

Besides the methods of bread making noted above there are others occasionally used. Jago[1] describes those employed by bakers in England and Scotland. The following statements are based on his description:

Ferment, sponge, and dough method.—As the name implies, this is a combination of the two methods last described. The ferment is mixed with the sponge, then, after this has stood for several hours, the rest of the flour and water are mixed in the sponge and dough fashion. There is, perhaps, a slight economy of yeast by this method, but it is very complicated, and therefore less certain.

A similar proceeding is sometimes practiced in the southern part of the United States, and is known as a "bleaching process," because the long rising is supposed to whiten the dough.

Scotch barm method.—This is not unlike the ferment, sponge, and dough system, "barm" taking the place of the other ferments. Barm is literally the foamy scum which rises to the top when beer, etc., is made. This may be used to ferment other materials. A variety of yeast is also called barm. To make barm in the household malt is crushed in warm water, hops and boiling water are poured over it, then flour is added, and the mixture is allowed to stand until the starch granules from the flour have been burst open by the hot water and the starch thus freed has been changed into sugar by the diastase of the malt. A sweet liquid is drained off from this and mixed with flour and water, the resulting sticky mass being subjected to the action of yeast, either acquired spontaneously by exposure to the air (virgin barm) or added in the form of a little old barm or ordinary yeast (Parisian barm). The fermentation thus started is allowed to continue several days and then the barm is ready for use in the sponge. A strong flour is needed for both the barm and the dough, and consequently the bread yield is large. In Scotland, where this method is almost universal, bakers consider it most economical, because there is practically no yeast to be bought and the flour used in the barm goes

[1] The Science and Art of Breadmaking, by William Jago, London, 1895.

into the bread. These arguments seem hardly tenable, however. The cost of labor in preparing the barm must be considerable and at least a portion of the flour in the barm is lost in the form of alcohol and carbon dioxid. Moreover, while the barm is exposed to the air in making it takes in a great many bacteria which start lactic and other fermentations and give a decidedly sour taste to the bread. To be sure, persons accustomed to such bread find an ordinary sweet loaf insipid. Still such a flavor would, it is probable, hardly be acceptable to the average American palate.

BREAD MADE WITH LEAVEN.

According to Boutroux,[1] the leaven used in France is easily prepared. A little of the dough ready for baking is saved and mixed with an equal amount of flour and water and is allowed to stand four or five hours; this operation is repeated three or four times before the leaven is ready to be mixed into the actual dough. This gradual mixing of the leaven is preferred, because in this way the yeast is allowed to act on one lot of flour only for a short time, then before it has become exhausted and other fermentations set in new yeast food is added, and thus a large number of yeast cells is supposed to be produced along with relatively few lactic and butyric bacteria. In spite of this precaution, bread made with leaven has a much more acid taste than that made with yeast, especially if the leaven has been kept some time. Anyone who has eaten the bread ordinarily made by the poor country people of France or Switzerland will willingly testify to this. More leaven is required in winter than in summer, because the yeast develops less quickly in cold weather, but on the average the leaven should form one-third of the entire dough. Bread made with leaven has large, irregular holes in its crumb. This is attributed to the fact that the bacteria in the leaven give rise to a ferment (diastase) and acids, which tend to soften the gluten.

Boutroux considers bread made with leaven more healthful than that made with yeast, because the acids it contains aid in its digestion. He also maintains that leaven is more reliable than the yeasts ordinarily found in the French market, but probably the majority of experts in this country would hold that the best of our compressed yeasts are more reliable and much more convenient. Whatever its practical value nowadays, bread made from leaven is interesting from the historical point of view, as it represents the way in which almost all the world made its bread from the time of the Pharaohs down to our own century. The following description[2] of bread making, as practiced by

[1] Le Pain et la panification. L. Boutroux, Paris, 1897.

[2] The Dawn of Civilization. Egypt and Chaldæa. G. Maspero. London: Soc. Prom. Christian Knowledge, 1897, 3 ed., p. 320.

a woman of ancient Egypt, shows that the principle was essentially the same then as now:

> She spread some handfuls of grain upon an oblong slab of stone, slightly hollowed on its upper surface, and proceeded to crush them with a smaller stone like a painter's muller, which she moistened from time to time. For an hour and more she labored; * * * but an indifferent result followed from the great exertion. The flour, made to undergo several grindings in this rustic mortar, was coarse, uneven, mixed with bran or whole grains which had escaped the pestle, and contaminated with dust and abraded particles of the stone. She kneaded it with a little water, blended with it, as a sort of yeast, a piece of stale dough of the day before, and made from the mass round cakes about half an inch thick and some 4 inches in diameter, which she placed upon a flat flint, covering them with hot ashes. The bread, imperfectly raised, often badly cooked, borrowed from the organic fuel under which it was buried a special odor and a taste * * *.

SPECIAL BREADS.

Besides the ordinary white bread described in the last section, there are innumerable fancy white breads, breads made from other flours than wheat, and unleavened breads on the market. So few analyses of them have been made, however, that they can be hardly more than enumerated here.

FANCY LEAVENED BREADS.

Most like the ordinary white bread are of course the fancy white ones, Vienna and French rolls, milk breads, etc. These usually differ chiefly in the use of milk, sugar, butter, lard, etc., in the dough. Entire wheat, graham, rye, barley, or oatmeal flours are made into bread in essentially the same way, and vary in texture and nutritive value according to their original composition. Soda, cream of tartar, or baking powder biscuits, shortcakes, etc., are intrinsically the same thing as ordinary white bread, except that the baking powder or its substitute does the work of yeast. Such breads do not require to be kneaded or set to rise, and bake very quickly, hence are very convenient when yeast is unobtainable or time is short. They never become so light and porous as yeast-made bread, however, and dry very quickly.

UNLEAVENED BREADS.

The most interesting of these is perhaps the passover bread, which has been used during passover week by orthodox Jews from the time of Moses until now. It is simply a mixture of flour and water, baked in small round cakes until it is dry and hard, and is not unlike plain water crackers. Pilot bread, or ship's biscuit, is another simple preparation of flour and water so cooked that it can be kept for any length of time. Crackers, or biscuits, as they are often called, especially in England, are also a variety, or, more correctly, innumerable varieties, of unleavened breads. Milk, butter, lard, spices, dried fruits—anything or everything desired to give them a particular consistency, color, or flavor—is mixed with the flour and water, and the dough is then passed through very ingenious cutting machines and quickly baked in a hot oven. Such crackers are a concentrated form of nourishment.

The original graham bread made without yeast from graham flour according to the receipt of its inventor, and not to be confounded with raised graham bread, is made by kneading the flour and water thoroughly, and allowing the dough to stand several hours before baking. It is heavier than ordinary yeast bread, but still has a few "holes" in it, due probably to fermentation started by bacteria accidentally present in the flour or the air; it is sweet and by no means unpalatable, but probably the nutritive value of its protein is lower than Dr. Graham supposed.

Gluten bread, as its name implies, contains the gluten of the flour from which more or less of the starch has been removed. To make it, strong flour and water are made into dough, which is pressed and strained under a stream of water until the starch has been worked out; it is then kneaded again and baked. It makes a light, elastic loaf, frequently prescribed for diabetic patients from whose diet it is considered desirable to exclude starch.

HOUSEHOLD METHODS OF BREAD MAKING.

In preceding paragraphs attention has been called to the methods of bread making followed by bakers. These differ from the household methods more in the quantities used than in the principles followed. Thus, a baker uses a large amount of flour and finds that mixing the dough and kneading it is much facilitated by machinery of different sorts. With the small quantities used in the household special machines for kneading, etc., are not commonly used. In different regions somewhat different ways of making bread in the household are popular, and, indeed, each bread maker is apt to believe she has some especially valuable way of mixing, kneading, etc. These differences are not as important as is sometimes supposed, and, as has been said, the general principles followed in bread making at home are the same as in bakeries. What are perhaps the two most popular ways of making bread at home are sometimes called the "quick-raising" method and the "slow-raising" method.

Quick-raising method.—A stiff dough is made of the flour, water, and yeast. It is thoroughly kneaded and is then allowed to rise until it doubles its bulk, when it is again kneaded thoroughly. After rising a second time it is baked. In the quick-raising process a large quantity of yeast is used, and the time of fermentation is only about two and a half hours. The baking is completed in about four or five hours after the bread is first started to rise.

Slow-raising method.—A batter is made of the flour, yeast, and water, which is allowed to ferment ten or fifteen hours, usually overnight. More flour is then added, the dough is kneaded until smooth, and then allowed to rise and is treated in the same way as in the first method. In the slow-raising method less yeast is used than in the short process, and the fermentation is carried on for a longer time. The usual temperature at which the fermentation thus takes place is perhaps not far from 70°.

Various forms of "raised biscuits," "hot bread," etc., are made in the household by adding shortening, milk, eggs, etc., to the dough, or by modifying in some way the process followed. Sometimes baking powder of some sort is used as a leavening agent instead of yeast, and the form of bread called "baking-powder biscuit," or by some similar name, is the result. An interesting variety of bread made without leavening is known as "Maryland" or "beaten" biscuit. A rather stiff dough is made from flour and water, or milk, with shortening and salt added. It is kneaded and then beaten or pounded, being frequently turned over and over until it looks light and puffy. The biscuits are then formed and baked. The folding and pounding of the dough incloses small quantities of air in numberless little blisters. These expand in baking and make the biscuit light and porous. The different kinds of bread from other grains than wheat, as "corn bread," "brown bread," "rye bread," "gems," etc., which are made in many households vary somewhat in different regions, but they all follow the same principles which govern the bread making from wheat flour—that is, the flour or meal is mixed to a dough with water or milk, and some leavening substance is generally added to make the dough porous. Eggs, sugar, shortening, etc., may be added, giving rise to the numerous varieties with which we are all familiar.

BAKING AND COOLING.

In the earliest days of bread making the dough was simply put into the ashes of the fire to bake; then came the ovens heated by a fire within, which are still used to some extent, and finally the elaborately constructed ovens which can be heated or cooled to any temperature by means of furnaces and ventilating devices around them. But whatever the structure of the oven, the changes which the bread undergoes while in it are essentially the same. It goes in a heavy, uniform mass and comes out a light body of increased volume with a crisp, dark exterior—the crust—and a firm, spongy interior—the crumb. Let us first see what happens in the crumb. This, of course, heats more slowly than the outside; indeed, the moisture which it contains prevents its temperature from rising much above the boiling point of water (212° F.). When first put into the oven the yeast continues working, but a temperature of 158° F. kills it. The gas in the dough, however, still expands and, forcing its way outward, enlarges the loaf and gives it a spongy appearance. The gluten becomes stiffened by the heat, so that even after the gas in the bubble-like pores has escaped the walls still retain their shape. The starch granules and perhaps the protein compounds undergo certain chemical changes which render them more digestible. Meanwhile the crust is becoming hard and dark; the heat changes its starch into stiff gum and sugar and dries out the moisture; the brown color is due to chemical changes known as "caramelization." Of course the proportion of crust to crumb varies with the size of the loaf. The accompanying table[1] gives the relative percentages by weight in loaves of different weight of German bread:

Comparative weight of crust and crumb in bread.

	Weight of loaf.	Crumb in loaf.	Crust in loaf.
	Grams.	*Per cent.*	*Per cent.*
Bread No. 1	398	55.2	44.8
Bread No. 2	880	59.7	40.3
Bread No. 3	1,783	64.3	35.7
Bread No. 4	1,998	71.2	28.8

The heat in the oven should not be too great, especially at first, or the outside of the bread will harden too quickly and the interior will not be done before the crust is thick and dark; further, the gas expanding in the crumb will be unable to escape through the crust and will lift up the latter, leaving great holes beneath it. To prevent too rapid formation of the crust bakers often moisten the tops of their loaves before putting them into the oven, or have devices for passing steam over them during the baking. The steam also changes some of the starch into a sort of gum on the top of the loaf and gives it the shiny look so often seen in Vienna bread. The same effect can be produced by moistening the top of the loaf just before it is taken from the oven. If his oven is not equally heated throughout, a baker usually puts his small loaves into the hottest part at first, as the crumb of these bakes more quickly and is in less danger of being underdone. When these are baked the larger loaves, whose crumb has baked gradually in the cooler parts, are moved into the warmer place and their crust is quickly hardened. In some large ovens the temperature is gradually raised during the baking; especially is this the case in the aërated bread factories. Aërated dough is mixed with cold water, and if it were immediately subjected to a high temperature the crust would form before the interior was more than warmed through. Accordingly, a peculiar oven is used, one end of which is heated much hotter than the other. Two cylinders, one at either end of the oven, are connected by an endless chain, on which the bread plates are hung; the dough is placed on the latter at the cooler end, and then is grad-

[1] Arranged from Birnbaum's Das Brotbacken. Braunschweig, 1878, p. 255.

ually swung over to the warmer end, the speed being regulated by the time needed for baking. This insures a thorough baking of the crumb, while the extreme heat at the last gives a good, crisp crust.

The temperature of an oven and the time required for baking depend upon the size of the loaves. Small biscuits or rolls can stand a much hotter oven and quicker baking than large loaves, which must be heated slowly and long. For ordinary purposes a baker heats his oven to 400°–500° F. and lets a pound loaf bake an hour or an hour and a quarter; small rolls perhaps half an hour. An experienced cook can tell when the oven is hot enough by putting the hand in, but a pyrometer, as a thermometer for measuring high temperature is called, makes a much safer guide for an ordinary person.

On being taken from the oven bread should be placed on slats or sieves so that the air can circulate about it until it is thoroughly cooled. By that time all the gas and steam which are likely to escape have done so, and the bread may be put away. Some housekeepers wrap their hot bread in cloths, but this is not advisable, not only because it makes the bread "taste of the cloth," but also because it shuts the steam up in the loaf and makes it damp and clammy—an excellent medium for cultivating mold.

Of course, as great cleanliness should be observed in handling and marketing bread as in making it. In some bakeries it is kept where the dust and dirt from the street can get to it, or sometimes bread is delivered in dirty baskets or carts. In this way disease germs and dirt may readily be brought into the home. In Germany this is sometimes avoided by slipping the loaves into parchment-paper bags as soon as they are taken from the oven. Some American bakers adopt similar plans; a frequent one is that of wrapping the bread in paraffin paper, which serves the double purpose of keeping out dirt and preventing the bread from drying.

CHEMICAL COMPOSITION.

The chemical composition of the finished loaf differs somewhat from that of the original ingredients. The following table shows the difference in composition between flour and bread:

Average composition of white bread and of the flour from which it was made.[1]

	Water.	Protein.	Fat.	Carbohydrates.	Ash.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Bread	35.3	9.2	1.3	53.1	1.1
Flour	12.0	11.4	1.0	75.1	.5

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 28 (rev. ed.).

The increase of water in the bread hardly needs explanation, since it is evidently due to the water added in making the dough. The use of butter or lard and salt probably accounts for the excess of fat and ash. The protein and carbohydrates lost doubtless went to nourish the yeast. Most of the carbon dioxid into which they were converted passed out of the bread. According to Birnbaum[1] the baked bread contains an average of 0.314 per cent of alcohol,[2] by no means all of that generated by the yeast (about 1 per cent, according to Snyder); part is evaporated and part is probably changed into acetic acid. The bacteria and other microscopic plants which accompanied the yeast doubtless took their share of the protein and carbohydrates, returning a part in the form of the characteristic acids and other bodies which they produce. Part of the starch in the crust has been changed into dextrin, and that in the crumb has become gelatinous or partly soluble. The gluten, as we have seen, has taken definite shape. This really means that it has coagulated very much as the white of an egg does in boiling.

STALE BREAD.

Good fresh bread has a crisp crust which breaks with a snap, and an elastic crumb which springs back into shape after being pressed with the finger. Before bread is a day old, however, its texture has changed; its crust has become softer and tougher, while the inside seems dry and crumbly, the bread is "growing stale," as we say. This was formerly supposed to be due simply to the drying of the bread, but as the loss of water is found by experiment to be comparatively slight, some other explanation is necessary. Various explanations have been offered, of which the most interesting seems that given by Boutroux in the work already quoted. He maintains that the apparent dryness is due to a shifting of the moisture from the crumb to the crust. When first taken from the oven the dry crust cools quickly, but the moist crumb retains its heat much longer. As gradually, however, its temperature falls to that of the surrounding atmosphere, its moisture tends to distill outward, leaving a comparatively dry crumb and moist crust. Common experience shows that if stale bread is put into the oven for a few minutes it regains something of its fresh consistency—a crisp crust and moist crumb. This fact would be explained by the reverse of Professor Boutroux's proposition; that is, the moisture is driven back into the crumb. Such warmed-over bread lacks the elasticity of the fresh loaf, and its interior crumbles as easily as before it was reheated. This is supposed to be because the starch has undergone a chemical change, the nature of which is not yet clearly understood. Indeed, the whole question of staleness is one about which little has been absolutely proved.

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[1] Das Brotbacken. Braunschweig, 1878, p. 252.

[2] On the other hand, Snyder found that no appreciable amount of alcohol remained in breads after baking. (U. S. Dept. Agr., Office of Experiment Stations Bul. 67, p. 16.)

IMPERFECTIONS AND IMPURITIES IN BREAD.

One of the most common and dangerous faults in bread is heaviness and sogginess. As we have seen, this may be caused by the use of cheap flours, poor in gluten, which can not absorb all the water put into the dough, or, to state it in another way, by the use of too much water in proportion to the flour; by too little or by too poor yeast; or by insufficient kneading, rising, or baking. Heavy bread is popularly considered one of the most indigestible of foods. When chewed it rolls itself into solid lumps, which give the saliva and gastric juices very little chance to work upon them.

Occasionally the crumb of fresh bread breaks when cut, instead of separating cleanly under the knife. According to Jago,[1] harsh dry flours, not sufficiently fermented, may be the cause of this, or the dough may have lost its tenacity by being overworked.

Another common fault in bread, especially in baker's bread, is a crumb full of large, irregular holes instead of the small, even pores which it should show. These occur in overkneaded or overraised dough, or if they are found just below the crust they mean that the oven was too hot and that the crust formed before the carbon dioxid had finished expanding.

Sometimes bread makers are troubled by what is known as "sticky" or "slimy" bread. In such cases bread three or four days old takes on a light-brown color and a peculiar taste and odor. Gradually, too, it becomes sticky or slimy until it may be pulled into strings, sometimes several feet in length. The trouble appears to be caused by the common potato bacillus (*Bacillus mesentericus vulgatus*), a minute organism which finds its way into the materials of the dough, survives the baking, and, growing in the bread, causes it to decompose. Experiments recently made at the Wisconsin Experiment Station[2] show that the bacilli enter the bread with the yeast, which in the cases investigated was a variety of the compressed yeasts ordinarily on the market. It was also proved that the bacilli will survive the heat of baking. Accordingly, if yeasts are not carefully made such trouble may occur at any time, but especially when the weather is warm and favorable to the growth of the bacilli. The best safeguards are to keep the bread in a cool place and to bake only as much as can be consumed within a day or two.

Not infrequently, especially in damp weather, mold forms on the outside, or even in the inside of bread. Mold, like yeast, is a minute plant whose spores (or seeds) are floating about everywhere in the air, ready to settle down and grow wherever they find a moist, suitable home for themselves. The best practical way to protect bread from them is to keep it in a dry, air-tight box.

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[1] The Science and Art of Breadmaking, by William Jago, London, 1895.

[2] Wisconsin Sta. Rpt. 1898, p. 110.

But all these faults seem insignificant compared to that dread of all bakers, sour bread. This is due to lactic, or, in the worst cases, butyric, acid given off by undesirable bacteria in their growth. A little acid is not necessarily harmful, as was seen in the discussion of bread made with leaven and barm; but when the acidity is very pronounced or even accompanied by putrefaction (developed in company with butyric acid) then something is radically wrong. Possibly the vessels in which the bread was made were not thoroughly cleaned after the last using and some of the undesirable bacteria got into the dough from them; or perhaps the yeast contained an undue proportion of these bacteria; or, if the latter were found only in normal quantities, possibly the yeast itself was weak and was quickly exhausted. The trouble may be due to the fact that the dough was allowed to stand too long after mixing, the yeast ceased working, and the dangerous bacteria which grow best in the presence of acetic acid, such as occurs after alcoholic fermentation has ceased, had gotten the upper hand. If none of these things are at fault, the undesirable bacteria may have come from the flour itself. Such cases are fortunately very rare, and if a baker guards against all the other dangers, he is pretty sure to make sweet bread. If bread grows sour with age it has probably caught the undesirable bacteria from the air, just as it catches mold. Very rarely, however, bread perfectly sweet at first grows sour before the bacteria in the air have had a chance to get at it. The only possible explanation for this is that the bacteria have managed to survive the baking and are growing luxuriantly in undisputed possession of the good things in the bread.

Besides these acid-producing bacteria, various others occur in bread, mostly harmless, but some of them very curious in their effects. Most striking among these is the *Micrococcus prodigiosus*, a minute organism which makes blood-red spots in the dough and whose presence gave rise to many interesting superstitions during the Middle Ages.

Aside from the adulterants mentioned in the section on flour, those most commonly met with in bread are mineral salts mixed into the dough for the purpose of producing a good-looking loaf from poor flour. Alum is the most common of these. It tends to check the action of the diastase and permits a weak flour to absorb more water than usual. It also improves the color of the bread. Many reliable bakers use it under the impression that it does good and not harm; but besides producing a bread whose nutritive value is not so great as appearances indicate, it is believed to be really injurious to the digestive system, and must be ranked as an objectionable adulterant. Alum tests are usually made by soaking a sample of the suspected bread in a solution of tincture of logwood and ammonium carbonate, in which alum betrays itself by a bluish color. Copper sulphate is used to produce an effect similar to that of alum in bread, but is believed to be more dangerous. Lime exerts practically the same influence and does no particular harm. Its use is reprehensible only because it gives poor bread the appearance of good bread.

Soda is often used in bread to prevent souring, and as it does not lessen the value can hardly be called an adulterant. In breads made from special flours poor in gluten—oatmeal, barley, etc.—soda is necessary in the production of a sweet, well-raised loaf.

NUTRITIVE VALUE AND COST OF BREAD.

COMPARISON OF THE COMPOSITION OF BREADS AND OTHER FOODS.

If we wish to know which of several foods furnishes the most actual nourishment for the least cost, we must know not only the actual price and the nutritive ingredients of each, but also their relative digestibility, and the one which is found to furnish the greatest amount of digestible nutrients for a given sum will be the cheapest.

To show the difference in the proportions of the different food ingredients in various foods, it may be well to compare the analyses of bread and other foods as given in the following table:

Composition of various food materials.[1]

	Number of analyses.	Refuse.	Water.	Protein.	Fat.	Carbohydrates.	Ash.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Corn bread (johnnycake)	5		38.9	7.9	4.7	46.3	2.2
Rye bread	21		35.7	9.0	.6	53.2	1.5
Rye and wheat bread	1		35.3	11.9	.3	51.5	1.0
Wheat bread, "gluten"	6		38.2	9.3	1.4	49.8	1.3
Wheat bread, "graham"	27		35.7	8.9	1.8	52.1	1.5
Wheat bread, "rolls"	20		29.2	8.9	4.1	56.7	1.1
Wheat bread from high-grade patent flour			32.9	8.7	1.4	56.5	.5
Wheat bread from regular patent flour			34.1	9.0	1.3	54.9	.7
Wheat bread from bakers' flour			39.1	10.6	1.2	48.3	.9
Wheat bread from low-grade flour			40.7	12.6	1.1	44.3	1.3
Wheat bread, average, all analyses	198		35.3	9.2	1.3	53.1	1.1
Whole wheat bread	12		38.4	9.7	.9	49.7	1.3
Crackers	71		6.8	10.7	8.8	71.9	1.8
Beef, ribs:							
Edible portion	15		55.5	17.5	26.6		.9
As purchased	8	16.8	39.6	12.7	30.6		.6
Veal, leg:							
Edible portion	19		71.7	20.7	6.7		1.1
As purchased	18	11.7	63.4	18.3	5.8		1.0
Mutton, leg:							
Edible portion	15		63.2	18.7	17.5		1.0
As purchased	15	17.7	51.9	15.4	14.5		.8
Cod steaks:							
Edible portion	1		79.7	18.7	.5		1.2
As purchased	1	9.2	72.4	17.0	.5		1.0
Hens' eggs:							
Edible portion	60		73.7	13.4	10.5		1.0
As purchased		11.2	65.5	11.9	9.3		.9
Butter			11.0	1.0	85.0		3.0
Milk, whole			87.0	3.3	4.0	5.0	.7
Potatoes:							
Edible portion	136		78.3	2.2	.1	18.4	1.0
As purchased		20.0	62.6	1.8	.1	14.7	.8
Apples:							
Edible portion	29		84.6	.4	.5	14.2	.3
As purchased		25.0	63.3	.3	.3	10.8	.3
Chocolate, as purchased	2		5.9	12.9	48.7	30.3	2.2

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 28 (rev. ed.)

From various dietary standards it is reckoned that the average man at moderate work requires about 0.28 lb. of protein to 0.28 lb. of fat and 0.99 lb. of carbohydrates in his daily food, which together furnish 3,500 calories of energy. The harder he works the more food he will need. Milk contains the three classes of nutrients, but not in the proper proportion for adults in health. The large quantities of milk which a man would have to drink in order to obtain the necessary amount of nourishment make it inconvenient for exclusive use. Meats are rich in protein. Vegetables are especially rich in carbohydrates. Bread contains the three classes of nutrients in about the right proportion; still in order to get the requisite amount of protein from it one would have to take more carbohydrates than is otherwise necessary. It must not be supposed that it is impossible to live without the three classes of foods in the given proportion. The poor of India and China and other Eastern countries often live almost entirely on cereals, and have become so accustomed to this diet that they refuse to change. They, however, secure more protein than is ordinarily supposed by the use of sauces, vegetable cheese, etc., made from legumes, notably soy beans.[1]

Turning to the bread analyses, we see that wheat bread from low-grade flour, wheat bread from bakers' flour, and rye-and-wheat bread contain the largest amount of protein; corn bread and wheat rolls, the most fat; and wheat rolls, wheat bread from high-grade patent flour, and wheat bread from regular patent flour, the most carbohydrates. The amount of fat would, of course, vary greatly with the amount of shortening added in making the bread, and the examination of a large number of analyses of the same kind of bread has shown that the amount of each of the several nutrients varies in the same sort of bread within rather wide limits. Judged by their composition, all breads are nutritious foods, and too great stress should not be laid on the variations in composition between the different kinds.

DIGESTIBILITY OF DIFFERENT KINDS OF BREAD.

The next question is, Which kind of bread furnishes the greatest amount of digestible nutrients? Unfortunately no experiments have been made with exactly the same materials as those represented in these tables, but investigations conducted on similar lines will not be without value in this connection.

Among the best known of such experiments are those conducted by Meyer and Voit, of Munich, about twenty-five years ago. Four kinds of bread were used: (1) Rye bread, raised with a leavening powder; (2) bread made from a mixture of rye and wheat flours and raised with yeast; (3) fine white bread raised with yeast, and (4) coarse whole-

[1] U. S. Dept. Agr., Farmers' Bul. 58, Appendix.

wheat bread, which the Germans call "pumpernickel," raised with yeast. The third of these, fine white bread, yielded the highest percentage of digestible nutrients, next came the wheat and rye bread, then the bread raised with the leavening powder, and last the pumpernickel. The pumpernickel may be left out of account, as it was too coarse to be justly compared with whole-wheat bread such as is made in the United States. The fine white bread was the lightest of the other three, next to it stood the rye and wheat, and last that raised with the powder, the same order that they took with regard to digestibility. These experiments prove, not so much the comparative value of different flours, as that the digestibility of bread depends largely upon its lightness.

Recent investigations conducted at the Maine Experiment Station[1] throw light on the question of comparative value of various kinds of bread. Experiments were carried on with several subjects with the following results:

Comparison of nutrients digested and energy utilized in different kinds of bread.[1]

Kind of food.	Number of experiments.	Nutrients digested.			Energy utilized.
		Protein.	Fat.	Carbohydrates.	
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
White bread alone	4	82	70.7	98.4	92.2
White bread with milk	9	88.3	66.6	98.2	94.8
Graham bread with milk	6	77	58.1	92.4	88
Entire-wheat bread with milk	5	86.6	46.2	97.2	94

[1] Maine Sta. Rpt. 1898, p. 207.

The figures in the last column, marked "energy utilized," were found by burning (in a bomb calorimeter) the equivalent of the food consumed and measuring the heat given off thereby, and from this calculating the heat which the amount digested should furnish. Heat and the energy of muscular work, voluntary and involuntary, are but different manifestations of the same force; consequently, using the proper factors, we may approximately determine the value of any food as a source of energy by measuring its heat of combustion.

From this table we infer that white bread yields the highest percentage of digestible nutrients; next comes entire wheat and last graham bread. (It should be stated that the graham bread used here was not the unleavened variety, but was made with yeast.) As was to be expected the whole-wheat breads made from carefully prepared flours proved much more digestible than the cheap pumpernickel used in the German experiments. It is also worth noticing that the entire wheat flour prepared without the three outer layers of the grain makes a more digestible bread than the graham flour containing the whole grain.

[1] Maine Sta. Rpt. 1898, p. 197.

Part of the experiments reported in this table were made with bread alone; the rest with bread and milk. This was because a man accustomed to a varied diet finds it impossible to digest or even to eat large quantities of bread alone. How much more nourishment he gains from the same amount of bread taken with milk may be seen by comparing the experiments with white bread alone with those with white bread and milk. In the Munich experiments the subject took beer and butter with his bread. In both cases the figures quoted were calculated to give the nutrients of the bread alone.

The amount of actual nourishment which a given weight of bread will furnish is found by multiplying the weights of its nutritive ingredients by their percentages of digestibility. Let us take the number of heat units or calories[1] which a gram of bread will give off when burned as the measure of its nutritive ingredients. From the tables given in the Maine Station Report these are found to average:

	Calories per gram.
White bread	2.83
Graham bread	2.55
Entire-wheat bread	2.65

Multiplying these by the percentage of energy utilized from each bread, we find that 1 gram of white bread eaten alone yielded 2.69 calories, eaten with milk, 2.78 calories; 1 gram of graham bread yielded 2.18 calories and 1 gram of entire-wheat bread 2.35 calories. From this point of view white bread is still the most advantageous. The chief argument for the entire wheat and graham flours is that they furnish larger amounts of protein, the kind of food in which bread is most lacking. Let us see what these Maine experiments say of this. From them we calculate that 1 gram of average white bread contains 0.086 gram of protein, graham bread 0.083 gram, and entire-wheat bread 0.086 gram. Multiplying these by the percentages of digestibility of protein, 1 gram of white bread with milk will furnish 0.076 gram of digestible protein, while the same weights of graham and entire-wheat bread will furnish, respectively, 0.064 and 0.074 gram. Thus we see that even in regard to the amount of protein digested, white bread is still the most valuable; next comes entire wheat and last graham bread.

As regards the claim that the bran-containing flours furnish valuable mineral matters and fats, it should be stated that as yet no experiments have been made to test the digestibility of these substances, and until that is done nothing positive can be said on either side. Too much stress should not be laid on the importance of the extra amount of phosphates and other ash constituents of bran. Fine flour also contains these same constituents and it is not unlikely that they are more

[1] A calorie represents the amount of heat necessary to raise a kilogram of water 1° C., or a pound of water 4° F.

available than in the bran, even if finely ground. These substances are of undoubted value, but there is little experimental data to show the amount of different ash constituents necessary for maintaining the body in health. It is doubtless safe to say that the ordinary mixed diet of children and adults furnishes an abundance of mineral matter. The coarser flours, with the particles of bran, often increase the peristaltic action of the intestine and thus tend to prevent constipation. They may at times otherwise aid digestion, hence for persons in need of a laxative, bread made from such flours may often be preferable to white flour, but for a healthy person its claim of superior value is very questionable. Certainly no plea can be made for them on the ground of economy, for entire-wheat and graham flours cost more than white flour.

The coarse flour used in the German bread called pumpernickel costs less, but it is doubtful whether a cent's worth of it furnishes as much nourishment as a cent's worth of white flour. The comparative digestibility of the various grades of white flour was recently investigated in Minnesota[1] and it was found that the difference between the amounts of digestible nutrients furnished by breads made from patent roller process and bakers' flours was very slight. Unfortunately there are no statistics at hand from which to compute the comparative cost of the digestible nutrients in rye, corn, and other breads. In German investigations recently made in reference to army bread[2] the conclusions are drawn that if complete digestion of the nutrients of the bread is the main object the cheaper grades of white flour are the most economical, but that if low cost is also an object, a mixture of rye and white flour is to be recommended.

Statements of a popular nature are frequently met with on the unwholesomeness of hot bread. The fact that bread is hot has doubtless little to do with the matter. New bread, especially that from a large loaf, may be readily compressed into more or less solid masses, and it is possible that such bread would be much less finely masticated than crumbly, stale bread, and that, therefore, it might offer more resistance to the digestive juices of the stomach. However, when such hot bread as rolls, biscuit, or other form in which the crust is very large in proportion to the crumb is eaten this objection has much less force. There is little difficulty in masticating the crust, and it is doubtless usually finely divided.

MARKET VALUE OF BREAD.

When we come to the actual market price of bread we find that it bears little relation to the nutritive ingredients or even to the cost of the materials. Experiments made at New Brunswick, N. J., and Pittsburg,

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 67, p. 34.
[2] Experiment Station Record, 10, p. 375.

Pa.,[1] tend to show that bakers in those sections set their prices by the size and trade name of the bread. Thus in New Brunswick, where fifty analyses were made, the bread containing the highest amount of nutrients and that containing the lowest were sold at exactly the same price per pound, 4.1 cents. In New Jersey it appeared that the larger the loaf the higher the cost per pound tended to rise. The average cost of bread seems to vary in different localities; thus, while the investigations just referred to were being carried on it averaged from 5 to 6 cents a pound in Middletown, Conn., from 3.8 to 4.9 in different cities in New Jersey, and 3.75 in Pittsburg.

When the selling price of bread and the cost of its ingredients are compared the results are still more striking. In two experiments made in New Jersey it was found that two lots of bread made from materials costing, respectively, $2.28 and $2.56 were sold for $5.86 and $6.08. This represents a profit of 116.5 per cent over the cost of the materials, or, to put it in dollars and cents, the baker received $216.50 for bread whose materials cost him $100. In Pittsburg the average increase in price over the original cost was 110 per cent. Even subtracting from this the cost of labor, rent, fuel, etc., the profits of the baker are so high that, to quote from the Pittsburg report, "It would seem that in the case of very poor families * * * an important pecuniary saving would result if bread was made at home. To the man in ordinary circumstances it must always be more a question of convenience and taste than of cost. In short, each family can best determine for itself whether it is desirable to pay the baker for the trouble of making the bread and delivering it, or whether the labor of making and the extra fuel for baking can best be provided at home."

SUMMARY.

Cereals of some kind or other have always made an important item of human food, and of all the forms in which they have been used bread has proved the most satisfactory, because the most digestible and appetizing, To prepare the grain for bread making it is usually cleansed, crushed, and sifted into a fine, soft powder which we call flour. Among various flours the preference should of course be given to the one which yields the most nutritious loaf for the least money.

The nutritive value of bread depends not only on its chemical composition, but also on its digestibility, and digestibility, in its turn, seems to depend largely on the lightness of the loaf. It is the gluten in a flour which gives it the power of stretching and rising as the gas from the yeast expands within it, and hence of making a light loaf. Rye, barley, and oats have less gluten than wheat, and maize has none, and therefore wheat, despite its higher cost, yields the most

[1] U. S. Dept. Agr., Office of Experiment Stations Buls. 35 and 52.

nutriment for a given sum. It is possible that of the various kinds of wheat flour those containing part of the bran—entire wheat and graham flours—furnish the body with more mineral matters than fine white flour, but they probably do not yield more digestible protein, as was for a time supposed. It seems safe to say that, as far as we yet know, for a given amount of money white flour yields the most actual nourishment with the various food ingredients in the best proportion.

The raising or leavening of bread is usually brought about by letting yeast develop in it. These minute plants feed upon sugar in the dough and in their growth give off alcohol and carbon dioxid gas, which latter, expanding with the heat, forces its way through the dough and thus lightens it. In order to give the yeast a better chance to work, the dough is usually "set to rise" for some hours before it is put into the oven. There are many methods of growing yeast at home or in the bakery, but the compressed yeasts now in the market seem to give equally good results with so much less labor that their use, in the United States at least, is becoming practically universal.

The lightness and sweetness of bread depend as much on the way in which it is made as on the materials used. The greatest care should be used in preparing and baking the dough and in cooking and keeping the finished bread. Heavy, badly raised bread is a very dangerous food, and unfortunately very common, and probably more indigestion has been caused by it than by all other badly cooked foods.

As compared with most meats and vegetables, bread has practically no waste and is very completely digested. It is too poor in protein to be fittingly used alone, but when used with due quantities of other foods it is invaluable, and well deserves its title of "the staff of life."

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